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ATMOSPHERIC TURBULENCE IN AVIATION.

by

G. A. CORBY.
(METEOROLOGICAL OFFICE)

METEOROLOGICAL RESEARCH COMMITTEE.
AIR MINISTRY

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1. The operational requirement

It has been the practice for many years in aviation forecasting for predictions of turbulence to be included in forecasts issued to pilots, and at the M.O. Training School forecasters are taught to do this. A clear requirement for such forecasts is contained in the I.C.A.O. Specifications for Meteorological Services for International Air Navigation. No similar document dealing with meteorological requirements for the R.A.F. exists, but broadly speaking the principles followed for both military and civil flying are much the same. The current I.C.A.O. Specifications require indications of turbulence (with an estimate of intensity) to be given to pilots. The indication is given either by the insertion of appropriate symbols on pictorial cross-section forecasts or in plain language on other forms. Criteria governing the amendment of forecasts on account of changes in the forecaster's expectations regarding turbulence have been prescribed by I.C.A.O. Furthermore, there is a formal requirement for the issue of warnings of turbulence to Air Traffic Control Centres for broadcast to all aircraft in the area, at the discretion of the flying control staff. In practice it is the present Met. Office policy to restrict such clear air turbulence warnings to the re-issue of aircraft reports of severe incidents actually received.

Forecasters, therefore, have an obligation to attempt forecasts of turbulence. Whilst most flying was confined to the lowest few thousand feet of the atmosphere, forecasts of turbulence could be based on subjective estimates derived largely from considerations of instability, wind strength, and surface roughness. Turbulence was (and is) forecast in strong winds, in unstable airmasses and particularly in heavy convective cloud. Moderate success is achieved in forecasting such mechanical and convective turbulence in the lowest few thousand feet and it is probable that there is no great dissatisfaction with the standard attained in this respect. Estimates of intensity are, however, highly subjective, being confined to the descriptions slight, moderate or heavy.

At higher levels, the position is far less satisfactory. At I.C.A.O. Divisional Meetings during recent years, considerable concern has been expressed regarding the lack of understanding of meteorological problems affecting high-level high-speed flight, in particular of high-level clear air turbulence. So far as forecasting is concerned, the obligation to attempt predictions applies at high as well as other levels. At present the forecaster can do little more than exploit the results of synoptic/statistical studies (notably those of Bannon) to indicate preferred locations of turbulence relative to jet streams. Unfortunately such indications are unreliable, since many jet streams contain no significant turbulence at all. It is not known to what extent such forecasts are attempted at M.O. outstations.

It is known that civil aircraft operating over Europe at levels around 400 mb. have suffered a number of disturbing turbulence incidents and that the

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forecasters at London Airport are unable to provide satisfactory advice in their flight forecasts. The extent to which high-level turbulence may constitute a hazard to future civil aircraft at higher levels is uncertain. It is likely that the problem will be more acute for civil aircraft than for the R.A.F. Military aircraft are stronger and must be operated in spite of the attendant risks and conditions whereas in civil aviation the safety and comfort of the passengers is a prime consideration.

Apart from the need for a better understanding of high altitude turbulence to assist in the operation of, and forecasting for, high level aircraft, the design of aircraft is also affected by lack of information. It is now well recognised that the behaviour of an aircraft in turbulent air is intimately dependent upon the response characteristics of the particular aircraft, especially of its fundamental frequencies. For example, Canberra pilots commonly report "cobblestone" turbulence having a frequency around 6 c.p.s. with often, in addition, a much slower yawing in the horizontal. According to Zbrozek (of R.A.E., Farnborough), these vibrations correspond with the natural modes of the aircraft about horizontal and vertical axes. Zbrozek is gravely concerned that future aircraft types may be even more seriously affected in this way, because of reduced damping and increased size, which lowers the fundamental frequencies of the aircraft. In the 1954 Report of the Gust Research Committee, the implications of the fact that the natural frequencies of an aircraft can be excited by turbulence, were highlighted as the most noteworthy item. The Committee were disturbed at the lack of knowledge of gusts to enable accurate predictions of the effect of turbulence on future aircraft. In their recommendations, the Committee recorded an urgent need for knowledge of the structure of gusts especially of those gusts which cause high frequency responses in fast aircraft. Concern on similar grounds is recorded in the proceedings of recent I.C.A.O. meetings and recommendations were made calling for continued reporting by transport aircraft, for continued research, for the development of suitable devices for recording turbulence in civil aircraft and for the development of techniques for the investigation of turbulence by the use of additional instruments attached to routine radio-sondes.

It is clear from the foregoing that our knowledge of high altitude turbulence is inadequate:-

(a) for the provision of guidance to aircraft operators for operational planning purposes,

(b) to enable forecasters to provide useful advice in day-to-day flight forecasting (even now and more so in the future),

(c) for the provision of important data bearing on the design of aircraft.

2. What is being done

(a) The scheme under which reports of high altitude turbulence are made by the pilots of R.A.F. aircraft is still in force and a steady supply of such reports continues to be received. In the past these have been sufficient to enable analyses of the distribution of turbulence with altitude and in relation to the jet stream to be carried out (e.g. Bannon, Jones). The nature of the data does not admit of investigations of the structure of the turbulence. Further analyses of similar type could be carried out from the further data accumulated, if desired.

(b) Measurements are being made at East Hill of the movement of smoke puffs at high levels. The direct aim is to assess the variability of wind over periods of the order of a few seconds; indirectly, some information on turbulence should emerge. An alternative method, which avoids the bias towards clear sky conditions, is provided by the radar tracking of small quantities of 'window'. This also makes possible measurements over longer intervals of time than with smoke puffs.

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At present no other active research on the topic is actually in progress in the Meteorological Office.

3. What could be done

(a) The large number of aircraft reports supplied by R.A.F. pilots in the past has been invaluable in making it possible to demonstrate the relation between high altitude turbulence and the jet stream, etc. The continuance of these reports is probably worth-while. These reports, however, are almost exclusively confined to the British Isles, and in addition they form an unsatisfactory statistical distribution owing to the unknown irregularities of the flying. It seems highly desirable that a similar fully organised scheme for reporting by civil pilots should be arranged; the advantage would be that information from a much wider geographical area would result and also the data would come from regular flying over known routes. The framework of such a scheme was laid down by I.C.A.O. in 1950 but the response has been negligible. Occasionally incidents come to light at debriefings but there is no organised routine reporting. A suitable form for the purpose was devised by I.C.A.O. and it may be profitable to approach British airlines and appeal to them to make the scheme a reality; a corresponding approach to the meteorological office at London Airport would be necessary. In any event, such data as are available, or which could be obtained from flight logs, should be examined. A study of reports from a much wider area than the British Isles might throw some light on the awkward question as to whether there is any relation between high altitude turbulence and topography. Almost certainly there is some relation, at least in many cases, but the evidence is inconclusive and existing data are inadequate to resolve the question.

(b) Arising from the Gust Research Committee's concern that the natural frequencies of an aircraft might be excited to a dangerous degree by turbulence (analogous to the "flutter" problem), it was recommended that there should be liaison between M.R.F. and the Aerodynamics Dept., R.A.E., with a view to fitting to the M.R.F. Canberra an accelerometer capable of recording high frequency oscillations (2-10 c.p.s.). Other accelerometers used by the M.R.F. do not cover the requisite frequency range. There is understood to be some prospect of a suitable accelerometer being made available and if this were done and the instrument were used as routine on all Canberra flights a useful body of data would be accumulated; certainly the Gust Research Committee's recommendation deserves to be actively followed up. It is understood that R.A.E. might be able to provide data on the response characteristics of the Canberra; this would make it theoretically possible to attempt the determination of the turbulence spectrum from accelerometer records. An indication of the probable behaviour in the same turbulence of any other aircraft whose response characteristics were known would then be possible.

The approach in some American work has been somewhat different. The spectrum of the turbulence in the horizontal has been determined by hot wire anemometry; isotropy has been assumed and thus the spectrum of the vertical components is also determined. If a suitable accelerometer record is also available, the response characteristics of the particular aircraft can be deduced. There are some doubts as to whether this technique can be successful, but experiments with work of this sort are probably justified.

The analysis and interpretation of data of these sorts would no doubt be difficult and highly specialised and it is for consideration whether such work should be attempted within the Meteorological Office, or whether it is more appropriate to an aerodynamicist. An alternative approach might be to try to exploit further the M.R.F. technique by which both vertical and horizontal turbulence velocities are measured by hot wire anemometry. Reliance on accelerometer records or the assumption of

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isotropy would not then be necessary, although they might be used as a check. However, the installation of hot wire anemometers in the Canberra might be very difficult. So far as is known, such work of this type as has been undertaken (both here and in America) has been confined to low levels. It should be mentioned also that past experience of the flight investigation of high level turbulence (e.g. Hislop and R.A.E.) suggests that it is an elusive phenomenon, that there would be many abortive flights and that progress would necessarily be slow.

In spite of the difficulties, work on the above lines appears essential if adequate guidance is to be provided to the designers of future aircraft.

(c) The Meteorological Office might with advantage use its influence to try and foster the I.C.A.O. recommendation regarding the fitting of accelerometers to civil aircraft, although it is understood that R.A.E. have already arranged the installation of accelerometers and fatigue meters in selected civil and R.A.F. aircraft and trial installations are now being made at two Bomber Command units.

(d) A few years ago the M.R.F. demonstrated the feasibility of making useful measurements from one aircraft of horizontal and vertical smoke trails laid from another aircraft. The elusiveness of high altitude turbulence would probably make this too ambitious and too expensive a method. It may be mentioned that an American group recently asked for information on this technique as they thought it might be promising for studying the fine structure of wind shear through jet streams.

(e) There are obviously serious difficulties to the I.C.A.O. suggestion regarding the fitting of turbulence measuring devices to routine radio-sondes and this may not be a profitable line to pursue. Nevertheless the possibility might be studied by the Instrument Development Division of the Meteorological Office. Scrase has of course shown that limited information on turbulence may be deduced from radio-sonde radar-wind ascents and the Gust Research Committee recently recommended that the method of following the motion of a balloon-borne target by G.L.VII radar should be pursued.